



Experimental studies of crevice corrosion for buried pipeline with disbonded coatings under cathodic protection



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ABSTRACT

Numerous fire and explosion accidents have occurred because of pipeline ruptures through the corrosion area. Coatings under cathodic protection (CP) have been recognized to prevent/mitigate potential pipeline corrosion. In this work, a wedge-shaped crevice assembly was developed to study the effect of cathodic protection on corrosion of 20# steel pipeline with disbonded coatings. Polarization potential, current density, solution pH value, and dissolved oxygen concentration were measured by using the simulation of crevice area with disbonded coatings. Results have demonstrated that CP cannot reach the crevice bottom which reduces the effectiveness of corrosion protection. This effectiveness depends on the crevice geometry and could be improved with the increase of crevice length and decrease of its mouth size. A potential difference always exists between the mouth area and inside crevice. The oxygen concentrations drop significantly inside crevice whether CP is applied or not. The solution pH values inside crevice increase with the time. The solution pH values are higher when the applied CP potentials are more negative. According to the experiments, the effectiveness of cathodic protection could also be improved through enhancement of the local solution alkalinity. The research provides necessary information to prevent potential pipeline ruptures due to crevice corrosion and therefore mitigate potential losses for oil and gas transportation in the process industries.

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1. Introduction

Buried pipeline transportation is considered as the most efficient way of transporting oil, gas and chemicals. It has a lower cost and is relatively reliable, but corrosion is a significant problem for its safe operation. Disbondment is one of the most failure modes of pipeline coatings. In spite of coating's condition, corrosive medium, such as gas, water, and chemical species in the coating gaps, forms electrochemical corrosion environment, which causes crevice corrosion or stress corrosion cracking to the pipeline (Muhlbaucer, 2004; Roberge, 2012). Generally, the synergistic system of coatings and cathodic protection (CP) has been recognized as the most effective method to protect pipelines from external corrosion in soil (Chen, Li, Du, & Cheng, 2009; Song, 2012a, 2012b). Pipeline corrosion occurs when the coating is disbonded away from a defect or

holiday. CP effect is reduced due to coating holidays and disbonded defects which appear to be a complete coating but produce electric shielding effect of cathode protection. The crevice corrosion of pipeline is also found to be related to the CP potential (Kennell & Evitts, 2009; Parker & Peattie, 1999). Theoretical model investigation into the effect on time, applied potentials, holiday size, geometric dimension and pH value of solution for crevice corrosion is very complicated (Sharland, 1987; Sharland & Tasker, 1988; Song & Sridhar, 2008). Therefore, it is necessary to carry out experimental research under simulated conditions to further understand the crevice corrosion behavior of pipeline steel under disbonded coatings in the presence of applied CPs.

Considerable research has been conducted to study external corrosion of underground pipelines under disbonded coatings with a defect. Tremendous attentions have been on the effects of CP on local electrochemical environment and corrosion of steel under disbonded coatings (Betts & Boulton, 1993; Sharland, 1987). For example, it was found that the pH and potential gradients were influenced by exposure time, applied potential, solution conductivity, and crevice geometry (Sridhar, Dunn, & Seth, 2001). The research indicated that under CP conditions the evident potential

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gradient resulting from the potential drop was concentrated at the crevice opening (Yan, Wang, Han, & Ke, 2007). A protective local environment induced by CP under disbonded coatings was characterized by an increase in pH and removal of Cl^- . After CP is removed, the protective effects can persist for a period of time, depending on the diffusion of soluble species (Yan et al., 2007). Peng et al. have investigated the effectiveness of cathodic protection at corrosion defects on an X100 steel pipeline using both experimental and theoretical methods (Peng, Xu, & Cheng, 2014). Corrosion of steel was claimed to occur preferentially inside crevice due to a separation of anodic and cathodic reaction with the depletion of dissolved oxygen in the crevice solution (Chen, 2009). A potential difference always exists between the open holiday area and inside crevice, reducing the CP effectiveness. Potential, pH and oxygen concentration were measured within a crevice which concluded that the electrochemical corrosion of pipeline steel is due to the gradual chemical and electrochemical changes produced along the crevice (Perdomo & Song, 2000). Song has also modeled the evolution of chemistry and the transient behavior of corrosion in the disbonded region (Song & Sridhar, 2008; Song, 2012a, 2012b).

In this work, a wedge-shaped crevice assembly simulated as crevice corrosion was used to further understand the corrosion behavior of pipeline steel with disbonded coatings under cathodic protection. The changes of potential and current of steel 20#, pH value, and oxygen content in the crevice with the simulated disbonded coatings were measured. The effects of CP potential, crevice thickness and the crevice corrosion behavior of steel 20# in a simulated soil solution were investigated to elucidate the mechanism of crevice corrosion under cathodic protections. The experimental results could be used to improve the cathodic protection effectiveness on pipeline steel with disbonded coatings and hence to mitigate the pipeline corrosion in the process industries.

2. Experimental

2.1. Materials

Test specimen were cut from a 20# steel pipe, with the chemical composition (wt.%): C 0.24, Si 0.37, Mn 0.65, S 0.035, Cr 0.25, P 0.035, Ni 0.25, Cu 0.25 and Fe 97.92. A three-electrode cell system was used for simulation of a crevice created by coating disbondment (Chen, 2009; Perdomo & Song, 2000), as shown in Fig. 1. The cell consisted of a 20# steel working electrode with 50 mm × 30 mm × 3 mm in dimension. The test solution was simulated as a soil solution (chemical composition of 0.0232 M NaCl + 0.0065 M Na_2SO_4 + 0.0599 M NaHCO_3), with a pH value of 8.55. The solution was made of analytical agent and distilled water. All tests were carried at room temperature (22 °C) and open to air.

2.2. Measurement

A saturated calomel electrode (SCE) was used as the reference electrode, and a graphite electrode as the counter electrode. A wedge plastic shim (0.30 mm, 0.45 mm and 0.60 mm in thickness) was used to make the crevice with a Lucite as a coating membrane. The plastic shim was adjustable to control the crevice width (Perdomo, Chabica, & Song, 2001; Xu et al., 2011). Three ports were drilled at an interval of 1 cm from the holiday with an interval of 15 cm along the Lucite block to position the microelectrodes for measurements of local potential, current, solution pH and oxygen concentration, respectively. During the test the polarization potentials of steel at individual ports were measured by microelectrodes when various CP potentials (−775 mV, −925 mV and −1075 mV) were applied (Chen, 2009; Xu, Sun, Yan, & Wang, 2013). The solution pH was measured ex-situ through a Thermo Orion 9863BN pH meter. The local oxygen

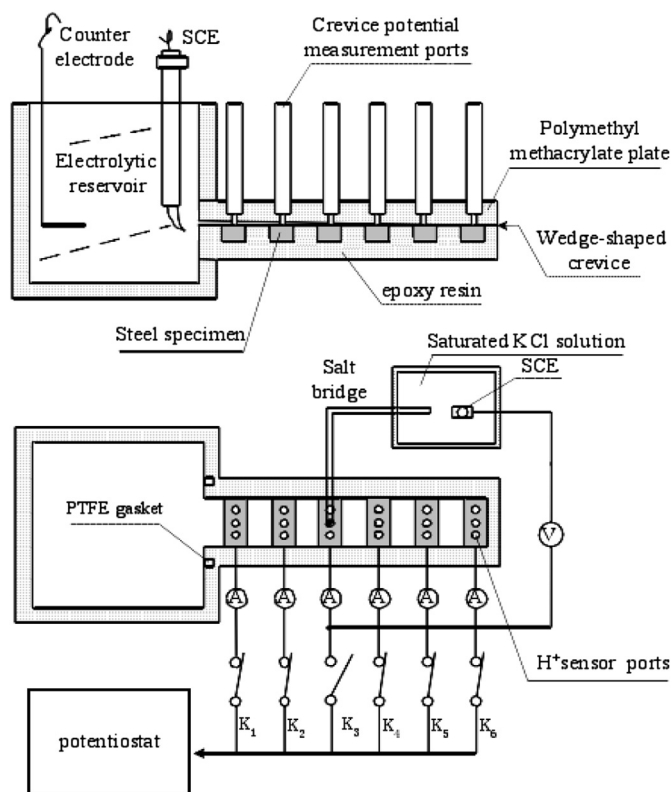


Fig. 1. Testing device of simulated crevice corrosion with cathodic polarization.

concentration was measured in-situ through a Unisense OX100 dissolved oxygen micro-glass electrode. The oxygen microelectrodes were sealed tightly with Lucite using a Sealant in order to avoid diffusion of oxygen through the port openings.

3. Results

3.1. Polarization potential distribution

Fig. 2 shows the polarization potential distribution in the crevice (mouth size $d = 45$ mm) with 33 h against different cathodic protection potentials (E_k), −775 mV, −925 mV and −1075 mV, respectively. It is shown that the polarization potentials of each point (expressed as E_{k1} , E_{k2} , E_{k3} , E_{k4} , E_{k5} , E_{k6} from the mouth to the bottom) in the crevice decreased with the increase of time and approached to CP potentials E_k , but they never reached CP potentials. Moreover, polarization potential of each point in the crevice increased with the increase of CP in the mouth of crevice, but decreased with the increase of distance from the mouth to the bottom of crevice.

3.2. Polarization current density distribution

Fig. 3 shows the polarization current density distribution in crevice (mouth size $d = 45$ mm) with 33 h against different CPs, −775 mV, −925 mV and −1075 mV, respectively, and the polarization current densities of each point from mouth to bottom in the crevice were expressed as i_1 , i_2 , i_3 , i_4 , i_5 , i_6 . It shows that i_1 is larger in the beginning, and the changed range is more than i_2 – i_6 toward the bottom of crevice with the increase of time, the polarization current density decreases and tends to be stable. Furthermore, the polarization potential increases with the increase of distance from the mouth of crevice but the polarization current density decreases in

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